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Underwater Treadmill Exercise as a Potential Treatment for Adults With Osteoarthritis

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This study examined the acute effects of underwater and land treadmill exercise on oxygen consumption (VO_2), perceived pain, and mobility. Nineteen participants diagnosed with osteoarthritis performed three consecutive exercise sessions for each mode of exercise. VO_2 and perceived pain were recorded during each exercise session and Timed Up & Go (TUG) scores were measured before and after each intervention. VO_2 values were not different between conditions during moderate intensities, but were 37% greater during low intensity exercise on land than in water ($p = .001$). Perceived pain and TUG scores were 140% and 240% greater, respectively, for land than underwater treadmill exercise ($p = .01$). Patients diagnosed with OA may walk on an underwater treadmill at a moderate intensity with less pain and equivalent energy expenditures compared with walking on a land based treadmill. Unexpectedly, OA patients displayed greater mobility after underwater than land treadmill exercise when assessed with the TUG.

An estimated 15% of Americans have some form of arthritis with osteoarthritis being the most common form (Lawrence et al., 2008). Osteoarthritis (OA) begins when joint cartilage breaks down, sometimes leaving a bone-on-bone joint. The joint then loses shape and bony growths develop. This degenerative process causes symptoms of pain and stiffness leading to difficulty in mobility, for example, when rising from a chair, climbing stairs, and walking. Generally, OA is an incurable disease with few effective treatments (Nieman, 2007).

Physical therapy treatment for OA patients aims at reducing pain and improving muscle strength, balance and joint coordination, and joint range of motion (Hurley, 2003). Physical therapy on land is a common treatment for OA; however, in recent years more attention has been devoted to evaluating the effectiveness of aquatic therapy. Research indicates there are many potential benefits of aquatic physical therapy compared with land-based therapy. For example, Hinman, Heywood, and Day (2007) noted that aquatic exercise may assist in pain relief, swelling reduction, and ease of movement due to the pressure and warmth of water. Hinman et al. also noted that patients with OA may be able to perform exercises that are too difficult on land because buoyancy may reduce pain across the affected joints. Some have argued the effects of water resistance make it possible to expend greater amounts

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of energy (Gleim & Nicholas, 1989; Hall, Macdonald, Maddison, & O'Hare, 1998) while still reducing stress and impact forces on the lower extremity joints (Barela & Duarte, 2008; Barela, Stolf, & Duarte, 2006).

There are many forms of aquatic exercise, including deep-water running, where runners are suspended in the water with a buoyancy vest or belt; shallow-water running, where participants run/walk in the shallow end of the pool; aerobic aquatic therapy, where participants perform a variety of calisthenics in the shallow or deep end of a pool; and, the most recent type of exercise, underwater treadmill exercise, where the water depth and treadmill speed are adjustable.

There are obvious benefits to being able to control water depth and treadmill speed, which are primary determinants of exercise intensity. For example, being able to objectively control exercise intensity between two modes of exercise (e.g., water versus land) may allow researchers to determine if differences in therapy outcomes are due to the environmental intervention itself or due to differences in exercise intensity. Previous research examining the effectiveness of aquatic therapy exercise in comparison with land based exercise in OA patients have not used an underwater treadmill, and therefore, have not been able to control water depth and gait speed (Ahern, Nicholls, Simionato, Clark, & Bond, 1995; Cochrane, Davey, & Matthes-Edwards, 2005; Foley, Halbert, Hewitt, & Crotty, 2003; Hinman et al., 2007; Lund et al., 2008; Norton, Hoobler, Welding, & Jensen, 1997; Wang, Belza, Thompson, Whitney, & Bennett, 2007; Wyatt, Milam, Manske, & Deere, 2001). We would postulate that some of the mixed results reported in the literature (Hinman et al., 2007; Lund et al., 2008; Wang et al., 2007) may in part be related to this lack of control over exercise intensity. This contention is supported by Gleim and Nicholas (1989), who observed that different water levels contribute to different energy expenditures in healthy adults. Currently, the effectiveness of using an underwater treadmill as a therapy protocol in patients with OA has not been tested

One of the challenges with prescribing underwater treadmill exercise in OA patients is determining a gait speed that may lead to therapeutic gains. Hall et al. (1998) reported that at treadmill speeds of 1.25 and 1.53 m/s, oxygen consumption (VO_2) was greater in water than on land for healthy females; and when walking speeds are below 0.97 m/s, VO_2 values were lower in water than on land in patients with rheumatoid arthritis (Hall, Grant, Blake, Taylor, & Garbutt, 2004). Due to pain and other demobilizing factors of OA, it is unknown if OA patients will be able to produce the same VO_2 response on an underwater treadmill versus a land treadmill matched for speed. In addition, it is important to standardize walking speeds between land and water to truly compare the cardiorespiratory and perceived pain responses during underwater and land treadmill exercise.

In view of these limitations of previous research, the purpose of this study was to examine the acute effects of underwater and land treadmill exercise on VO_2 and perceived pain in OA patients. Because functional measurements are essential for determining the efficacy of any treatment, and because mobility is often compromised in OA patients (Cichy & Wilk, 2006; Hinman, Bennell, Metcalf, & Crossley, 2002), we also examined how each mode of exercise influenced gait kinematics and Timed Up & Go performance. It was hypothesized that underwater treadmill walking would elicit the same VO_2 response as land treadmill walking at the same speed. This hypothesis is based on the observations by Rutledge, Silvers, Browder, and Dolny (2007) who observed that VO_2 values in healthy adults are no different between land and underwater treadmill running when the water depth was set to the xiphoid process. Regarding pain and mobility, we hypothesized that pain would decrease after walking on the underwater treadmill, and mobility would remain the same after both the aquatic and land exercise interventions. This hypothesis is based on the observations by Barela and Duarte (2008), who reported a lower ground reaction force and a slower stride frequency for elderly individuals while waking in water immersed to the xiphoid process. If OA patients experience less pain and greater mobility after underwater treadmill walking with comparable VO_2 values than land treadmill walking, this mode of aquatic physical therapy may be suitable for treating OA patients.

Method

Participants

Potential participants for this study were recruited from the local community through flyers and informational sheets distributed through primary care physician offices. Before participating in the study, all participants read and signed an informed consent form approved by the University Institutional Review Board.

To be included in the study, participants had to be previously diagnosed with knee, hip, or ankle OA through clinical history, physical examination, and radiographic analysis. All diagnoses were made by a local rheumatologist and were confirmed for "definite" OA based on a diagnostic algorithm (March, Schwarz, Carfrae, & Bagge 1998). In addition, participants had to be over 35 years of age, able to walk a city block, and walk up stairs in a reciprocal manner. Participants were excluded if they currently exercised on an underwater treadmill, had intra-articular corticosteroid injections in the past month, reported any neuromuscular disease such as Parkinson's disease, stroke, cardiovascular disorders or surgeries to the lower limb (except for exploratory arthroscopy), lavage of knee joint or partial meniscetomy at least one year before entry into study. Nineteen participants who responded to the request for subjects met these criteria. Physical characteristics and arthritis history for the participants are reported in Table 1.

Procedures

This preliminary study used a quasi-experimental crossover design to address the study purpose. Each participant was asked to perform three consecutive exercise sessions on an underwater treadmill (Figure 1); HydroWorx 2000, Middletown,

Table 1 Physical Characteristics for all Participants (*n* = 19, 3 Male and 16 Female)

Characteristic	Mean	*SD*	Range
Age (yr)	59.4	7.4	43–70
Height (cm)	160.3	8.22	157–188
Body mass (kg)	90.8	21.8	54.5–145
Involved limb (s)	2 hip, 12 knee, 2 ankle, 1 hip/knee, 1hip/ankle, 1 knee/ankle		
Duration of OA (yr)	7.88	6.73	2–24

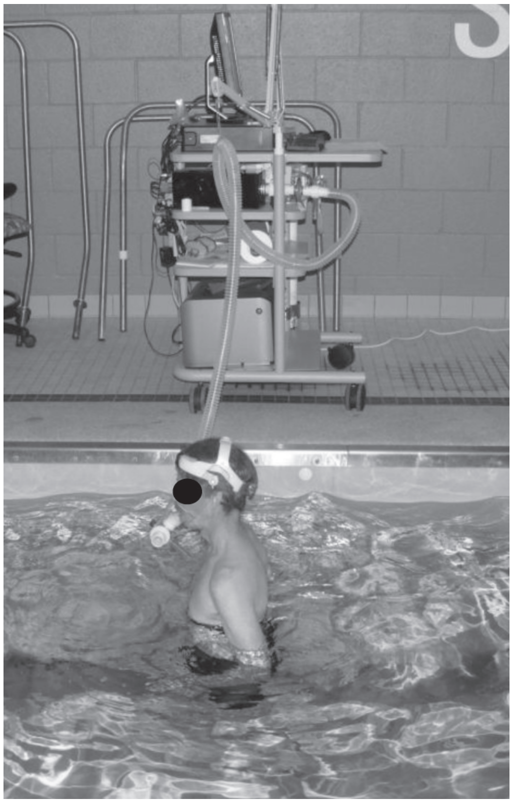

Figure 1 — Experimental set-up for the underwater treadmill mode.

PA) and on a land based treadmill (Nordic Track 9600, ICON Fitness, Logan UT). Each exercise bout was separated by at least 24 hr and was completed within one week. Each mode of exercise was separated by one week. The order of exercise mode was randomly assigned. It was determined from pilot testing that three exercise sessions were appropriate to provide familiarization with procedures and equipment and to realize any acute effects of mode exposure.

The amount of walking for each exercise bout was 20 min and consisted of four 5 min stages (Table 2). The first stage (the self-selected pace) required participants to walk at a self selected pace they considered "comfortable." The second stage was 0.13 m/s faster than the self-selected pace, and the third stage was 0.26 m/s faster than the self-selected pace. The fourth stage speed was identical to the first stage speed. Participants performed the underwater treadmill exercise with no shoes at a water depth equal to the xiphoid process. The temperature of the water was 30°C with the air temperature set at 24°C. The land treadmill exercise was performed in the same room and in the same manner as the underwater treadmill exercise and required participants to wear their normal walking shoes along with typical exercise clothing. Treadmill incline was set at 0° for each mode of exercise. To assess the relationship in nominal speed settings between the underwater and land treadmills, a video analysis of belt speeds were examined. An interclass correlation coefficient (ICC = 0.99) performed on the analyzed data indicated nominal speed settings were similar between treadmills.

Table 2 Rating of Perceived Exertion (RPE) and Volume of Oxygen Consumed (VO_2; mean ± *SD*) During Each 5 min Stage of the 20 min Exercise for Underwater (Aquatic) and Land Treadmill Exercise

	RPE		VO_2 ($l \cdot min^{-1}$)	
	Aquatic	Land	Aquatic	Land
Stage 1 (≈ 0.78 m/s)	1.41 (1.20)	1.50 (1.07)		
Stage 2 (≈ 0.91 m/s)	2.68 (1.64)	2.60 (1.15)		
Stage 3 (≈ 1.04 m/s)	3.74 (1.84)	3.77 (1.24)	1.00 (0.32)	1.15 (0.23)
Stage 4 (≈ 0.78 m/s)	1.88 (1.59)	2.17 (1.05)	0.71 (0.22) [a]	0.97 (0.21)

Note. All values are recorded from the third exercise session. Stage 1 = self selected pace; Stage 2 = self selected pace + 0.13 m/s; Stage 3 = self selected pace + 0.26 m/s; Stage 4 = same speed as stage 1. [a]significantly different from land treadmill exercise, $p < .05$.

Measurements

Cardiorespiratory. The VO_2 was recorded during the third exercise session of each mode of exercise using a computerized metabolic measurement system (Figure 1; Parvomedics True One 2400, Sandy UT). Calculations of VO_2 ($l \cdot min^{-1}$ STPD) were made from expired air samples taken from participants breathing through a two-way valve mouthpiece (Hans Rudolph 700 series, Kansas City MO). Measurements of VO_2 from the third exercise session were calculated every 15 s during the third and fourth stage of the 20 min exercise bout and were averaged over the last 2 min of each stage. Before each testing session, O_2 and CO_2 analyzers from the metabolic system were calibrated with known gas mixtures and the pneumotach was calibrated with a 3 l syringe using manufacturer guidelines. As a supplement to the VO_2 data, rating of perceived exertion (RPE) was recorded during the third exercise session for all stages.

Pain Scale. The perception of joint pain was assessed immediately before and after each exercise session using a continuous visual analog scale. The scale was 12 cm in length and was modeled after pain scales described previously (Carlsson, 1983). The left end of the scale was labeled “no pain” and the right end was labeled “very severe pain.” To improve consistency of implementing the pain scale, we provided written instructions to each participant before they rated their pain. The instructions were, “please mark the line to indicate the arthritis related joint pain that you feel right now; the further to the right, the more discomfort/pain you feel.” Visual analog scales, such as the one used in this study, are reported to be reliable assessments of pain perceptions and are more precise than ordinal scales that rank responses (Carlsson, 1983; Gramling & Elliott, 1992; McCormack, Horne, & Sheather, 1988). The pain scales were analyzed by measuring the distance from the left of the scale to the vertical mark drawn by each subject. This distance was measured to the nearest millimeter. All preexercise pain scores were averaged, and all postexercise pain scores were averaged, to yield a single mean pain score before and after each mode of exercise.

Gait Kinematics. Gait analyses were assessed at baseline (within 24 hr of beginning the exercise week) and within 24 hr of completing the third exercise session for each mode of exercise. Gait kinematics was assessed using a motion analysis system that tracked retro-reflective markers placed on the subject (Vicon MX system, Vicon Motion Systems, Centennial, CO, USA). Participants walked four times at their preferred speed over a flat straight 10 m course using their normal walking shoes. Seven Vicon T-20 cameras sampling at 100 Hz tracked the low mass (2.2 g) retro-reflective markers placed on the skin over select bony landmarks of the foot and leg. Three-dimensional position data from each reflective marker were computed from direct linear transformations using Vicon Nexus software. From the position data, stride length was computed as the rectilinear distance (m) between 2 successive placements of the same foot and stride rate was computed as the frequency of the stride (strides/s). On average, six consecutive strides for both limbs were averaged and recorded.

Timed Up & Go (TUG). The TUG is a simple method to assess basic mobility and balance (Podsiadlo & Richardson, 1991). We recorded TUG data at baseline and after completing the third exercise session for each mode of exercise. Instructions for how to complete the test were first given to the participant and then demonstrated by an investigator. The instructions were to stand up from an armed chair with a seat of 45 cm from the floor, walk 3 m at a comfortable speed, cross a line on the floor, turn around, walk back, and sit down again. The TUG was timed in seconds using an ordinary stopwatch with timing commencing when the participant's back was no longer in contact with the back of the chair and stopping when their buttocks touched the seat of the chair when they returned. The TUG has been reported to be a reliable and valid tool for mobility and balance assessments (Podsiadlo & Richardson, 1991; Shumway-Cook, Brauer, & Woollacott, 2000).

Statistical Analyses

Self selected treadmill speeds for the underwater and land treadmill were compared with a Paired-Samples *t* test and arthritis history information (e.g., time since diagnosis) was analyzed descriptively. The independent variable in this study was mode of exercise (underwater treadmill or land treadmill) and the dependent variables were VO_2, RPE, perceived pain, gait kinematics (stride length and stride rate), and TUG. When pre and post measures were available, a gain score was computed and used for statistical comparisons between conditions. Gain scores may provide reliable insight into individual differences between conditions and are appropriate when variability may be high within participants (Williams & Zimmerman, 1996; Zimmerman & Williams 1982). For example, OA patients often display high variability in perceived pain between days (Hochberg et al., 1995), preventing a stable base for comparisons. In the current study, positive gain scores will indicate that pretest scores are greater than posttest scores and negative gain scores will indicate the opposite.

The nonparametric Wilcoxon signed rank test was used to compare VO_2, RPE, perceived pain, gait kinematics, and TUG scores between conditions with an alpha set at 0.05. Effect sizes (ES) were also quantified to appreciate the meaningfulness of any statistical differences. The ES were calculated with the following formula: ES = (high value—low value) / (standard deviation of high value), and Cohen's (1988) convention for effect size interpretation was used (< 0.41 = small, 0.41–0.7 = medium, and > 0.7 = large).

Results

Data from all participants were used in the statistical analyses, although some data (i.e., post underwater treadmill data) were missing from one participant who was unable to complete testing due to scheduling conflicts. Pairwise comparisons of the self selected speeds indicated they were not different between underwater (0.76 ± 0.24 m/s) and land (0.80 ± 0.26 m/s) treadmill exercise ($p = .13$). The descriptive results from arthritis history questionnaire revealed that, on average, the amount of time between the diagnosis and testing in our laboratory was 7.88 (± 6.73) yrs and that the knee was the primary arthritic joint (Table 1).

The VO_2 values were not different between conditions during stage 3 ($p = 0.08$), but were 37% greater during the preferred walking speed (stage 4) on land than in water ($p = 0.001$; ES = 1.24; Table 2). The RPE scores followed a similar trend to the VO_2 values but were not different between conditions ($p = 0.59$; Table 2). Perceived pain and TUG gain scores were 140% and 240% greater, respectively, after land compared with after underwater treadmill exercise ($p = 0.01, 0.02$; ES = 0.49, 1.12; Table 3) and gait kinematic (i.e., stride rate and stride length) gain scores were not different between conditions ($p = 0.16–0.74$; Table 4).

Table 3 Perceived pain and Timed Up & Go (TUG) Scores (Mean ± *SD*) During Underwater (Aquatic) and Land Treadmill Exercise

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Pain (mm)	24.5 (19.7)	17.3 (15.0)	19.8 (16.4)	26.1 (13.3)	3.36 (10.3)[a]	-8.19 (10.3)
TUG (s)	12.3 (6.32)	11.2 (3.99)	11.4 (3.98)	11.7 (5.15)	0.83 (2.85)[a]	-0.55 (1.38)

Note. Gain scores were computed as the difference between pretest and posttest values. [a]significantly different from land treadmill exercise, $p < .05$.

Table 4 Gait Kinematic Gain Scores (Mean ± *SD*) for the Right and Left Limbs During Underwater (Aquatic) and Land Treadmill Conditions

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
SL (m)						
Right	1.15 (0.44)	1.09 (0.44)	1.17 (0.24)	1.09 (0.21)	-0.03 (0.31)	-0.15 (0.42)
Left	1.13 (0.42)	1.09 (0.41)	1.20 (0.24)	1.21 (0.21)	0.29 (0.71)	0.00 (0.65)
SR (strides/s)						
Right	0.90 (0.32)	0.91 (0.10)	0.89 (0.13)	0.88 (0.11)	0.42 (1.13)	0.03 (0.06)
Left	0.89 (0.11)	0.91 (0.10)	0.88 (0.13)	0.88 (0.11)	0.27 (0.44)	0.12 (0.29)

Note. SL = stride length and SR = stride rate. Gain scores were computed as the difference between pretest and posttest values.

Discussion

The unique aspect of this study was the control over the type, intensity, and dosage of exercise between water and land conditions. Most previous studies have not controlled for these confounding factors, which makes valid comparisons difficult. Results of this preliminary study indicated that patients diagnosed with OA may walk on an underwater treadmill at a moderate intensity with less pain and equivalent energy expenditures, compared with walking on a land based treadmill at a similar moderate intensity. Unexpectedly, OA patients displayed greater mobility and balance levels after underwater than land treadmill exercise when assessed with the TUG test.

It should be noted that energy expenditures (VO_2) were actually lower during underwater than land treadmill exercise at the participant's preferred walking speed. This result suggests the fluid resistance of water was not substantial enough at the slower walking speeds to counteract the cardiorespiratory relief created by the force of buoyancy. This contention is supported by previous research, which indicated that walking at speeds less than 0.97 m/s, buoyancy dominates and less energy is expended in water than land because fluid resistance is relatively low due to low limb velocities (Hall et al., 2004). When speeds are greater than 0.97 m/s, limb velocities increase and fluid resistance may offset buoyancy and lead to similar energy expenditures during water and land treadmill exercise (Gleim & Nicholas, 1989; Hall et al., 2004; Hall et al., 1998; Rutledge et al., 2007). The results of the current study support this observation. An important application of these results is that underwater treadmill exercise may help with weight regulation in OA patients, since this mode of exercise does not seem to diminish energy expenditure when speeds approach 1.04 m/s (Table 2).

One of the most important outcome measures in determining the efficacy of any physical therapy treatment for OA patients is reduced pain (Edmonds, 2009; Hurley, 2003). It was observed in the current study that perceived joint pain was less after aquatic versus land exercise, suggesting that underwater treadmill exercise may be efficacious for OA patients. The mechanism for this reduced pain is unknown but may be related to aquatic factors such as buoyancy, hydrostatic pressure, and temperature. Prior studies examining the effectiveness of aquatic therapy have not always observed reductions in pain after physical therapy (Lund et al., 2008; Wang et al., 2007). Discrepancies between studies may be related to a number of factors including the type of assessment and when it was administered. For example, visual analog scales are commonly used scales but vary in respect to the targeted pain. That is, bodily pain (Wang et al., 2007), pain during rest and walking (Lund et al., 2008), and joint specific pain (Cochrane et al., 2005; Hinman et al., 2007) have all been assessed with different outcomes. The present study assessed the joint specific pain immediately before and after the exercise. It is possible the acute nature of this study and the specific versus general pain targeted, may account for some discrepancies.

In addition to joint pain, OA patients often display compromised mobility in comparison with controls (Cichy & Wilk, 2006). For example, knee and hip OA patients often display compromised balance scores (Hinman et al., 2002) and reduced gait speeds secondary to decreased step lengths when compared with controls (Messier, 1994). We observed that mobility, based on the TUG, is improved after short term underwater versus land treadmill exercise. The results could not be explained by improvements in stride length and stride rate as these measures were not different between conditions. Researchers have previously noted that success of the TUG is related to strength and balance changes (Podsiadlo & Richardson, 1991). In this respect, the gains we observed may be similar to the acute neuromuscular gains observed after starting a resistance training program and would suggest that aquatic gait may produce greater acute effects in strength and balance than land treadmill exercise.

The results of the current study should be interpreted in light of the limitations of the study. For example, OA participants were tested before, during, and after only three exercise sessions; a longer training period may result in physiological and biomechanical adaptations that may change the outcomes of the study. It was clear from pilot testing that participants felt more comfortable after the second visit for each condition and that VO_2 and RPE measures were lower during the third visit, suggesting that a total of 40 min was a sufficient familiarization period.

Subjective comments from the participants of the study were all in favor of the underwater versus land treadmill exercise. Most participants commented that they felt good in the water and generally wanted to continue training on the underwater treadmill after the study ended. Unfortunately, due to the sparse access to underwater treadmills, most participants were unable to continue. We feel this is perhaps a temporary negative aspect of underwater treadmill therapy, in that OA patients may benefit from this form of exercise but are unable to find or have access to an underwater treadmill facility.

Conclusion

We concluded that patients diagnosed with OA will display similar energy expenditures during short-term exercise on an underwater versus land treadmill when speeds are greater than preferred. This finding along with the perceived pain findings would indicate that patients with OA may receive the same aerobic conditioning during underwater treadmill exercise with less joint pain than performing the same exercise on land. While future longitudinal research is needed, underwater treadmill exercise may also lead to greater improvements in mobility when compared with the same exercise performed on land.

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